

NEARBY YOUNG STARS SELECTED BY PROPER MOTION. I. FOUR NEW MEMBERS OF THE β PICTORIS MOVING GROUP FROM THE TYCHO-2 CATALOG.^{1,2}

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ABSTRACT

We describe a procedure to identify stars from nearby moving groups and associations out of catalogs of stars with large proper motions. We show that from the mean motion vector of a known or suspected moving group, one can identify additional members of the group based on proper motion data and photometry in the optical and infrared, with minimal contamination from background field stars. We demonstrate this technique by conducting a search for low-mass members of the β Pictoris moving group in the Tycho-2 catalog. All known members of the moving group are easily recovered, and a list of 51 possible candidates is generated. Moving group membership is evaluated for 33 candidates based on X-ray flux from *ROSAT*, H α line emission, and radial velocity measurement from high-resolution infrared spectra obtained at *Infrared Telescope Facility*. We confirm three of the candidates to be new members of the group: TYC 1186-706-1, TYC 7443-1102-1, and TYC 2211-1309-1 which are late-K and early-M dwarfs 45-60pc from the Sun. We also identify a common proper motion companion to the known β Pictoris Moving Group member TYC 7443-1102-1, at a $26''.3$ separation; the new companion is associated with the X-ray source 1RXS J195602.8-320720. We argue that the present technique could be applied to other large proper motion catalogs to identify most of the elusive, low-mass members of known nearby moving groups and associations.

Subject headings: astrometry – stars: emission-line, Be – stars: kinematics – stars: pre-main sequence – open clusters and associations: individual (β Pictoris Moving Group)

1. INTRODUCTION

Young stars are critical in understanding not just the star-formation process itself but also the formation of planetary systems, through observation of their circumstellar environment (Jayawardhana et al. 1999; Metchev et al. 2004; Liu et al. 2004; Zuckerman & Song 2004a; Weinberger et al. 2004; Chen et al. 2005). This is most efficiently achieved from the nearest possible vantage point, which makes nearby young stars very sought-after targets (Gaidos 1998; Montes et al. 2001a; Wichmann et al. 2003; King et al. 2003; Zuckerman & Song 2004b; Torres et al. 2008). Nearby young stars have become prime targets to achieve direct exoplanet imaging (Neuhäuser et al. 2003; McCarthy & Zuckerman 2004; Masciadri et al. 2005; Lowrance et al. 2005; Lafrenière 2007; Daemgen et al. 2007; Kasper et al. 2007) because massive planets are expected to be much more easily detected in their youth at a time when they still shine bright from their own gravitational collapse.

Young stars are known to exist in the vicinity of the Sun as members of “moving groups”, each consisting in loose associations of stars moving in the same approximate direction within the solar neighborhood. Proposed nearby moving groups and associations include the Castor moving group (Barrado y Navascués 1998; Ribas 2003), the β Pictoris moving group (Zuckerman et al. 2001), the Tucana/Horologium

association (Song et al. 2003), the AB Doradus moving group (Zuckerman et al. 2004), the Carina-Near moving group (Zuckerman et al. 2006), and notably the very young TW Hydrae association (Webb et al. 1999; Sterzik et al. 1999; Song et al. 2003) whose probable members include several brown dwarfs (Gizis 2002; Scholz et al. 2005; Looper et al. 2007). All of these nearby moving groups and associations are suspected to be dispersed fragments from a larger neighboring OB association (Berghöfer & Breitschwerdt 2002; Ortega et al. 2004; Makarov 2007).

Stars from nearby moving groups and associations are identified and confirmed through a combination of kinematic data and evidence of youth. Most of the original members were identified based on their full (three dimensional) kinematics provided by accurate proper motion and parallax from the Hipparcos catalog (Perryman et al. 1997), complemented with radial velocity observations. While it is relatively straightforward to identify moving group members among samples of stars for which both proper motion *and* parallax data exist, it is more complicated to search for members among field stars with no parallax data in hand. Proper motion measurements are now widely available for vast numbers of stars from all-sky proper motion catalogs such as Tycho-2 (Høg et al. 2000), USNO-B1.0 (Monet et al. 2003), or SUPERBLINK (Lépine & Shara 2005), but parallax and radial velocity measurements remain relatively rare, particularly for stars with visual magnitude $V \gtrsim 10$ mag. As a result, one must rely on secondary diagnostics, such as unambiguous signs of youth, to search for moving group members. Young low-mass stars are expected to have faster rates of rotation and thus higher coronal activity through a stronger dynamo effect (Montes et al. 2001b; Kastner et al. 2003). High coronal activity is associated with strong emission lines of atomic hydrogen and large X-ray emission. Spectroscopic follow-up of X-ray sources from the *ROSAT* catalogs has yielded positive identification of many nearby young stars, including

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new members of the TW Hydrae association (Tachihara et al. 2003) and the β Pictoris moving group (Torres et al. 2006). However, the *ROSAT* catalogs are flux limited, and though they are useful in identifying nearby young stars, they cannot serve as the basis for a *complete census* of moving group members.

It is telling that most confirmed members of young moving groups consist in stars of spectral subtype F, G, or K, and include few low-mass stars of spectral type M. Assuming those groups to follow the standard initial mass function, one would expect them to have significantly larger numbers of associated low-mass stars. Such low-mass members arguably are particularly promising targets for exoplanet surveys (López-Santiago et al. 2006) because the detectability of planets of a given mass is improved when the parent star has low intrinsic luminosity.

In this paper, we develop a general technique to identify new members of known moving groups among stars listed in large proper motion catalogs. We demonstrate the technique by performing a search for new members of the β Pictoris moving group (BPMG), using a subsample of stars from the Tycho-2 catalog (Høg et al. 2000) with proper motions $\mu > 70$ mas yr⁻¹. The general method is described in Section 2. A list of candidates members of the β Pictoris moving group is identified in Section 3. Follow-up spectroscopic observations are described in Section 4, and new β Pictoris members are identified. Conclusions follow in Section 5.

2. PROPER MOTION SELECTION METHOD

Let $\vec{V}_{\text{mg}} = U_{\text{mg}}\hat{x} + V_{\text{mg}}\hat{y} + W_{\text{mg}}\hat{z}$ be the mean motion of a local moving group, in the local standard of rest, with \hat{x} a unit vector pointing in the direction of the Galactic center, \hat{y} in the direction of the Sun's Galactic orbital motion, and \hat{z} pointing toward the north Galactic pole. At any point on the sky described by the Galactic coordinates (l, b) , one can calculate the local projected motion in the plane of the sky ($v_{l\text{mg}}, v_{b\text{mg}}$) of the moving group in the direction of Galactic longitude l and Galactic latitude b from

$$v_{l\text{mg}} = -U_{\text{mg}} \sin(l) + V_{\text{mg}} \cos(l) \quad (1)$$

$$v_{b\text{mg}} = -U_{\text{mg}} \cos(l) \sin(b) - V_{\text{mg}} \sin(l) \sin(b) + W_{\text{mg}} \cos(b). \quad (2)$$

In Galactic coordinates, the angle Φ that this vector ($v_{l\text{mg}}, v_{b\text{mg}}$) subtends with a star's local proper motion vector (μ_l, μ_b) is

$$\cos(\Phi) = \frac{\mu_l v_{l\text{mg}} + \mu_b v_{b\text{mg}}}{(\mu_l^2 + \mu_b^2)^{\frac{1}{2}} (v_{l\text{mg}}^2 + v_{b\text{mg}}^2)^{\frac{1}{2}}}, \quad (3)$$

which is easily derived from the definition of the scalar product of the two vectors. Stars which are actual members of the moving groups will have their proper motion vector closely aligned with the projected motion of the group, and will thus have $\cos(\Phi) \simeq 1.0$. One can thus sift through a proper motion catalog and search for potential members of the moving groups by considering only the stars whose proper motion vector is within a few degrees of the expected orientation of the projected motion of the moving group. This restriction can be expressed simply as:

$$\cos(\Phi) > \cos(\Phi_{\text{max}}) \equiv Z_{\text{max}}. \quad (4)$$

The particular choice of Φ_{max} (or Z_{max}) will depend on the accuracy of the catalog's proper motions, and also on the dispersion in velocities between stars of the moving group. For

example, $Z_{\text{max}} = 0.985$ would restrict the sample only to stars whose proper motion is within $\approx 10^\circ$ of the expected projected motion of the moving group. A value of Z_{max} closer to 1.0 will considerably restrict the search, but may overlook some actual members. A smaller value of Z_{max} will be more likely to include all members of the group, but will also produce a larger sample with more contaminants.

Proper motion aligned in the direction of the projected motion of the moving group is however not a sufficient condition for a star to be a member of the group, because a given proper motion vector may correspond to a range of transverse velocities, depending on the star's distance. If the distance d to the star is known, then an actual member of the moving group will also verify:

$$\mu = (\mu_l^2 + \mu_b^2)^{\frac{1}{2}} \simeq 0.211 d^{-1} (v_{l\text{mg}}^2 + v_{b\text{mg}}^2)^{\frac{1}{2}}, \quad (5)$$

with $v_{l\text{mg}}$ and $v_{b\text{mg}}$ given by Eqs.1-2 above, and where the velocities are in km s⁻¹ and the distance d in parsecs. However, distances are generally not known for stars in proper motion catalogs, the one notable exception being the *Hipparcos* catalog. For a star with no recorded distance, it is however possible to constrain the distance based on color-magnitude relationships. If one assumes that a star is a member of the moving group, then it is possible to get an accurate distance estimate for that star based on the magnitude of the proper motion alone; this hypothetical distance can then be checked for consistency using color-magnitude relationships. Assuming that one given proper motion star is also a member of the moving group, then its hypothetical, *kinematically derived* distance d_{kin} will be

$$d_{\text{kin}} \simeq 0.211 (v_{l\text{mg}}^2 + v_{b\text{mg}}^2)^{\frac{1}{2}} (\mu_l^2 + \mu_b^2)^{-\frac{1}{2}}. \quad (6)$$

If d_{kin} is found to be inconsistent with some other distance estimate, such as a photometric distance, a spectroscopic distance or better yet a parallax distance, then the star can be ruled out as a possible member of the moving group.

Unless parallax measurements are already available for the candidate star, it is useful to compare d_{kin} with the photometric distance. Consider the visual magnitude V of a proper motion star and its infrared K magnitude, if the object is a main-sequence star, then it can be expected to follow a color-magnitude relationship $M_K = M_K(V - K)$ whose form depends on the age of the star. If a star is a member of the moving group under consideration, and assuming interstellar extinction to be negligible (generally valid for nearby stars), then one expects

$$K + 5 \log(d_{\text{kin}}) + 5 - M_K(V - K) \lesssim \sigma_K, \quad (7)$$

where σ_K is the mean dispersion about the color-magnitude relationship for members of that particular moving group.

An additional test is to verify that the radial velocity of the prospective moving group member is also consistent with group membership. A moving group member can be predicted to have a radial velocity $v_{r\text{mg}}$ such that

$$v_{r\text{mg}} = +U_{\text{mg}} \cos(l) \cos(b) + V_{\text{mg}} \sin(l) \cos(b) + W_{\text{mg}} \sin(b). \quad (8)$$

This prediction can be tested with radial velocity measurements.

Ultimately, one would want to confirm group membership by accurately measuring the *UVW* components of velocity of the source, which requires accurate distance measurement through geometric parallax as well as accurate radial velocities from high-resolution spectroscopy (Montes et al.

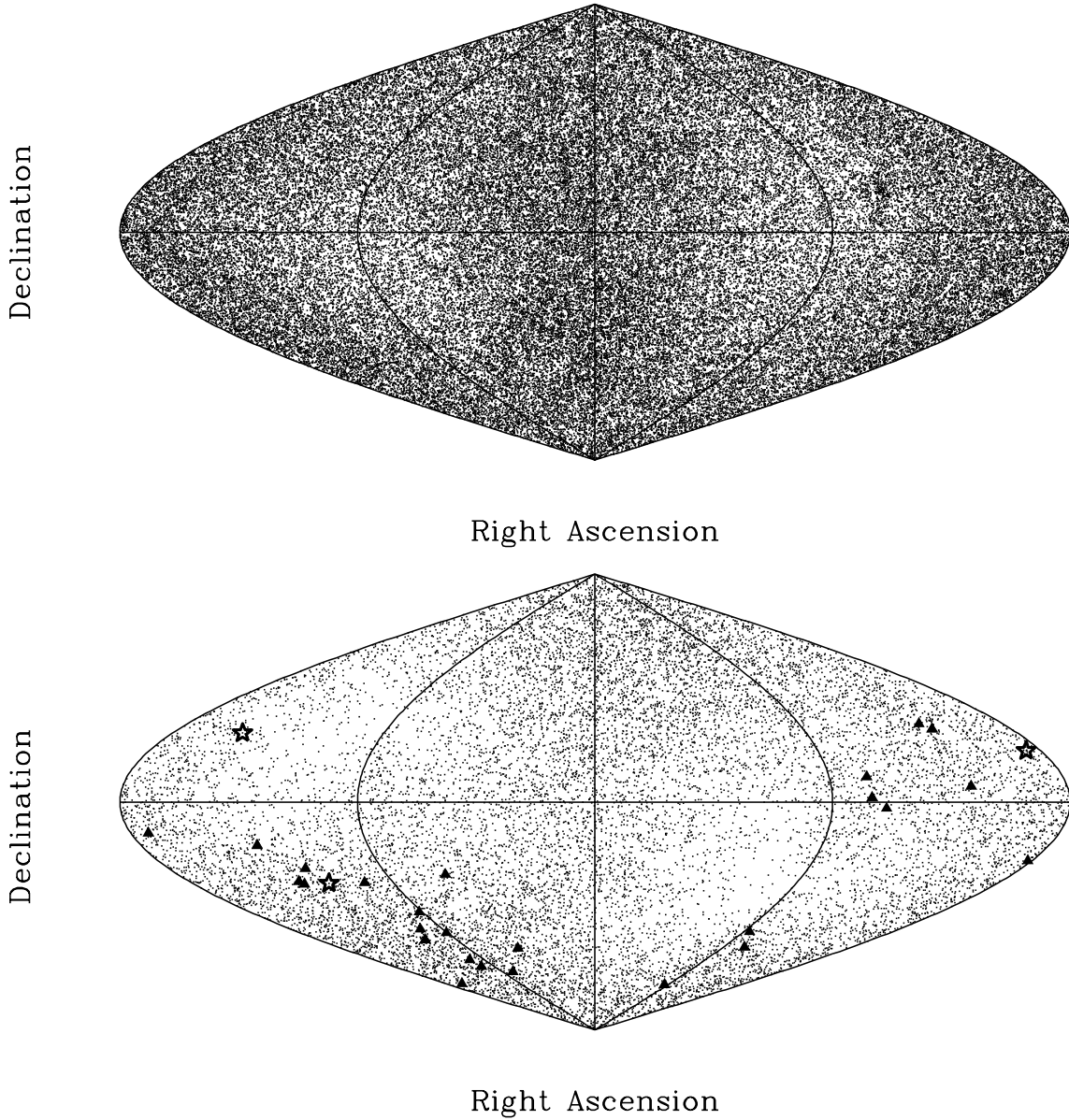


FIG. 1.— Top: distribution on the sky of the 86,626 stars in the Tycho-2 catalog which have proper motions $\mu > 70 \text{ mas yr}^{-1}$, each dot representing a star. Note the nonuniform distribution which is a result of the Sun's systemic motion through the local standard of rest and the systemic drift of thick disk and halo stars. Bottom: the subsample of 15,989 stars whose proper motion angle is consistent with membership in the β Pictoris moving group (proper motion angle within 12° of the local projected vector of the mean β Pictoris group motion). 29 known β Pictoris members are recovered in the process (triangles). Open star symbols show the locations of the three new confirmed member systems.

2001b). Additionally, moderate- to high-resolution spectroscopy should be used to check for the presence of lithium in the atmosphere (Li I $\lambda 6708$ in emission) which is a strong diagnostic for young age as Li is progressively depleted over time in low-mass stars (Michaud & Charbonneau 1991).

However such a detailed analysis of candidate members is expensive. High-resolution spectroscopy of moderately faint stars requires long observing times and/or large telescope apertures, and parallax measurements are intensive and require years of careful monitoring. It would be desirable to pre-select stars with the highest predicted likelihood of being moving group members. Such stars are expected to display

secondary evidence of youth, which includes evidence for atmospheric activity such as X-ray flux or $H\alpha$ line emission. While activity in itself does not necessarily imply that a star is young, a high proportion of the most active stars are found to be young objects (Jeffries 1995).

The above equations and practical considerations provide a road map for identifying elusive members of a known moving group out of a statistically complete catalog of stars with large proper motion.

1. Isolate a subsample of high proper motion stars whose proper motion vector points in the expected direction for the moving group (Eq. 4).

2. Identify stars from that subsample for which photometric data shows a match between the hypothetical kinematic distance and the photometric distance (Eq.7).
3. Reduce the sample further by selecting targets showing evidence for activity, such as strong X-ray or H α emission.
4. Compare the predicted radial velocity (Eq.8) to radial velocity measurements to identify probable kinematic members of the group.
5. Confirm kinematic membership through parallax measurements
6. Confirm young age through detection of Li I $\lambda 6707$.

In Section 3 below, we provide a demonstration of steps 1-4, applied to a subsample of bright high proper motion stars.

3. A SEARCH FOR β PICTORIS MOVING GROUP MEMBERS IN THE TYCHO-2 CATALOG

We demonstrate the technique described above by performing a search for members of the β Pictoris moving group in a subsample of high proper motion stars from the Tycho-2 catalog of Høg et al. (2000). We have assembled a list of 86,626 stars with proper motions $\mu > 70$ mas yr $^{-1}$; their distribution on the sky is shown in Figure 1 (*top panel*). This represents an all-sky sample of relatively bright stars. All objects are listed with Tycho-2 visual magnitudes $V_T < 14.0$ mag, with 90.7% of the stars in the $V_T < 12.0$ mag range. We have used the VizieR service⁶ and additional software of our own to cross-correlate the entire list with the Two Micron All-Sky Survey (2MASS) All-Sky Catalog of Point Sources (Skrutskie et al. 2006) and obtain infrared J , H , and K_s magnitudes for all the stars (a $10''$ search radius was used, and proper motions taken into account; most counterparts were recovered within $2''$ of their extrapolated position).

3.1. Proper motion selection

The first selection cut selects for stars which have a proper motion vector whose orientation is consistent with BPMG membership. We adopt as the fiducial space motion of the BPMG the mean motion of its known members, estimated by Torres et al. (2006) to be $(U_{\text{mg}}, V_{\text{mg}}, W_{\text{mg}}) = (-10.1, -15.9, -9.1)$ km s $^{-1}$ relative to the Sun. We apply Eq. 3, and select Tycho-2 stars whose proper motion vector makes an angle $\Phi < 12^\circ$ with the local projected BPMG motion vector ($Z_{\text{max}}=0.978$). This reduces the sample to 15,989 stars (18.4% of the initial sample) whose proper motion vector is aligned with the local projected motion of the BPMG. Their distribution on the sky is shown in Figure 1 (*bottom panel*). The distribution shows a dipolar moment, whose axis is aligned along the apex of the BPMG motion.

We have compared our list of proper motion selected objects to the 51 known members of the BPMG listed in Torres et al. (2006) and Torres et al. (2008). We find that we recover 30 of the known members. Of the 22 stars that are not recovered, we find nine stars that are too faint to be listed in the Tycho-2 catalog (8 of them being faint companions of recovered group members). Ten other stars have proper motions smaller than the proper motion limit of our initial sample ($\mu > 70$ mas yr $^{-1}$) and thus could also not possibly have been

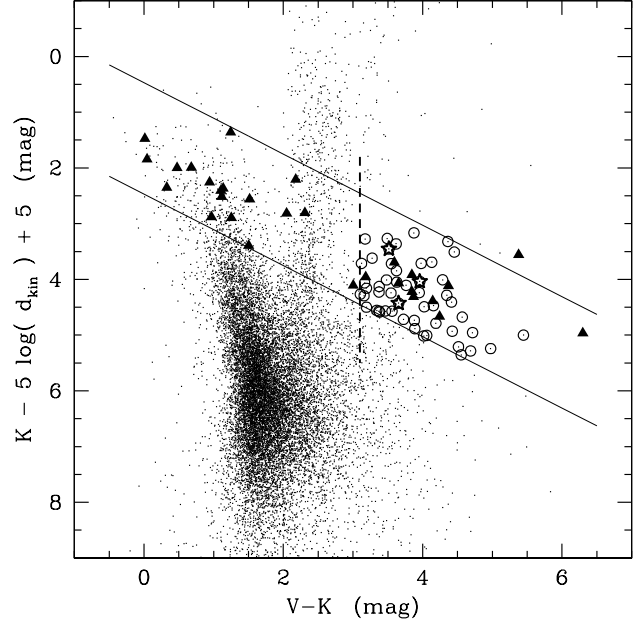


FIG. 2.— Color-magnitude diagram of the 15,989 stars with proper motions angles consistent with β Pictoris group membership, with kinematic distances (d_{kin}) calculated under the assumption that all stars are group members. The 30 known group members (triangles) are aligned along the expected main sequence for young stars of that age. Stars which do not fall close to that locus have inconsistent d_{kin} values, and can be rejected as unlikely group members. A high level of contamination from distant giants is observed around $V_T - K_s \simeq 2.5$. We have identified 51 very red objects ($V_T - K_s > 3.1$) as low-mass stars with a high potential for group membership (open symbols). 33 are investigated further in this paper; the three candidates confirmed in this paper to be very likely group members are plotted with five-pointed star symbols.

recovered. The two remaining stars are bright high proper motion stars which are listed in the *Hipparcos* catalog but, for some reason, are missing from the Tycho-2.⁷ All stars being accounted for, we then find our proper motion selection algorithm to have a recovery rate of 100%. This suggests that any unrecognized groups member that is present in the initial sample will be selected in the proper motion cut.

The 30 recovered members are listed in Table 1, and their location on the sky is indicated in Figure 1 with solid triangles. A majority of the members are located in the southern sky, with a concentration around $(\alpha, \delta) \sim (270^\circ, -45^\circ)$. However this moving group extends over a broad swath of the sky, and even has a few members north of the celestial equator. It even is possible that the Sun could be situated within the confines of the group. Hence, any of the 15,962 other stars could potentially be a β Pictoris member, regardless of its position on the sky.

3.2. Kinematic distance selection

The largest reduction in the number of possible BPMG candidates is achieved through kinematic distance selection. Based on data from the *Hipparcos* catalog, we calculate that the median transverse velocity of stars with proper motion $\mu > 70$ mas yr $^{-1}$ is $\simeq 47$ km s $^{-1}$. The mean motion of the BPMG is only 29 km s $^{-1}$, which means that field stars are moving faster on average, and thus d_{kin} will tend to underestimate their distances, making field stars appear underlumi-

⁶ <http://webviz.u-strasbg.fr/viz-bin/VizieR>

⁷ The two *Hipparcos* stars missing from the Tycho-2 catalog are HIP 12545 and HIP 112312.

nous.

Figure 2 shows the color-magnitude diagram for all 15,989 Tycho-2 stars identified as possible members, with d_{kin} used to calculate a pseudo absolute magnitude. The figure reveals that known group members occupy a distinct locus in this color-magnitude diagram, with most members following a relatively well defined color-magnitude relationship. This is not unexpected, as the calculated d_{kin} should be very close to the actual distance d to those stars. We find that one can model the mean locus of the BPMG members with

$$K_s - 5\log(d_{\text{kin}}) + 5 = 1.6 + 0.65(V_T - K_s) \quad (9)$$

with all members but one falling within ± 1 mag of this line.

As expected, the vast majority of stars in the overall sample do not cluster along the line defined in Eq.9, but appear significantly underluminous in the color-magnitude diagram. Nonmembers may fall off the well-defined locus of the group members for two main reasons: (1) their calculated d_{kin} either underestimate or overestimate their true distance, and/or (2) the stars are significantly older than BPMG members, and do not follow the same color-magnitude relationship as the young BPMG stars. From Figure 2, we see that most stars fall well below the standard color-magnitude relationship of BPMG members, most probably because d_{kin} significantly underestimate their true distance. All these background stars can be efficiently eliminated from the list of prospective candidates.

We find that of the initial 15,962 prospective members, only 835 fall within ± 1 mag of the mean color-magnitude relationship of BPMG members. This reduces the list of possible candidates by a factor of 20. The much reduced subsample, however, remains contaminated by a significant number of background giants which are easily identified in the color-magnitude diagram. These appear to be red clump K giants, with optical-infrared colors $2 \lesssim V_T - K_s \lesssim 3$. In Figure 2, they show up as a nearly vertical band of stars extending all the way up the diagram. These stars are a serious source of contaminants, however they occupy a fairly narrow range of colors. Since we are mostly interested in identifying the elusive low-mass members of the BPMG, we can further restrict our search to stars with very red colors, thus eliminating most of those K giants. We introduce $V_T - K_s > 3.1$ as additional color cut (dashed line in Figure 2). This further reduces the sample to a short list of 55 probable *low-mass* BPMG members. Such a sample is of a size very much manageable for follow-up spectroscopic programs.

A search of the literature reveals that four of the 55 candidates are actually known members of the TW Hya association (TWA). The reason for their presence among BPMG candidates is due to the fact that the TWA mean motion vector $(U, V, W)_{\text{TWA}} \simeq (-11.0, -18.0, -5.0)$ km s $^{-1}$ (Zuckerman & Song 2004b) is very close to the mean motion vector of the BPMG $(U, V, W)_{\text{BPMG}} \simeq (-10.1, -15.9, -9.1)$ km s $^{-1}$ (Torres et al. 2006). In many directions on the sky, the two associations run nearly parallel to each other, which makes confusion possible. Both groups also contain young stars, and occupy similar loci in the color-magnitude diagram. The four TWA interlopers are listed in Table 1.

Of the 51 remaining candidates, we proceeded to investigate further 33 objects which were within range for our follow-up spectroscopic observations (see below). This short list of 33 candidates is provided in Table 2. Follow-up observations are now being planned for the remaining 18 targets, which will be presented in a separate paper.

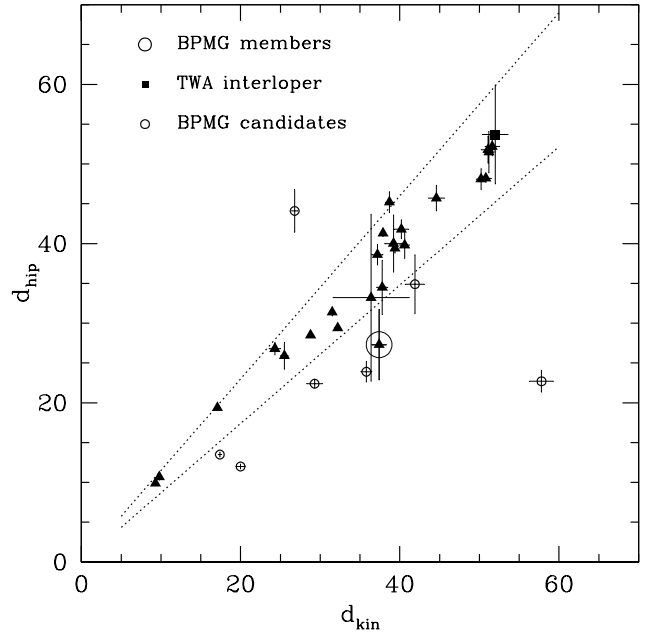


FIG. 3.— Comparison between the kinematic distance d_{kin} of recovered and prospective members of the BPMG, and their distances based on Hipparcos parallax d_{hip} . All previously known members (triangles) have both quantities agreeing to within 15% except for BD+28°382B (circled) whose distance is underestimated by Hipparcos (see the text). The solid square shows the location of the one TWA interloper with Hipparcos parallax (it is TW Hya itself).

4. CONFIRMATION OF NEW BPMG MEMBERS

4.1. Hipparcos parallaxes

Table 2 compiles data on the 33 candidates followed up in this paper. The table lists the Tycho-2 catalog (TYC) identifier, HIP numbers for stars listed in the *Hipparcos* catalog, coordinates in the ICRS system, proper motions, Tycho-2 visual magnitude V_T and 2MASS infrared K_s magnitude. The table also lists the predicted distances assuming BPMG membership (d_{kin} , based on the proper motion).

Though parallaxes are not generally available for stars in the Tycho-2 catalog, most of the brighter ($V_T < 10$) entries are also *Hipparcos* stars, and accurate parallaxes exist for them. In Tables 1 and 2, we identify all the *Hipparcos* objects by their catalog number, and provide distances (d_{hip}) based on their *Hipparcos* parallaxes as obtained from the recent new reduction of van Leeuwen (2007). Distances derived from these parallaxes are also tabulated; they are generally accurate to ± 1 -2 parsecs, though a few have large uncertainties, including TYC 689-130-3 (= [RHG95]853, =LP 476-207) whose estimated distance is 33.2 ± 10.5 pc. Additionally, the parallax to BD+28°382B, the resolved companion to HD 14082, is clearly overestimated in the van Leeuwen (2007) catalog, as it is quoted to be 36.58 ± 5.83 mas, compared with 28.97 ± 2.88 mas for HD 14082.

Figure 3 plots d_{hip} against the kinematic distance d_{kin} , calculated from the proper motion assuming all stars to be moving with the mean motion of the β -Pictoris moving group (Equation 6). We provide uncertainties on d_{kin} which are based on the uncertainties in the Tycho-2 proper motions. The relative errors on the proper motions are systematically smaller than those on the parallaxes, which yield smaller errors on d_{kin} than on d_{hip} . One should keep in mind, however, that the d_{kin} assume the stars to be moving exactly at the mean

motion of the group, which may not be strictly accurate because group members have some dispersion about the mean velocity. We find that all confirmed BPMG members have d_{hip} within 20% of d_{kin} . The small scatter is due to parallax and proper motion accuracies, but also to the intrinsic velocity dispersion of individual group members which is unaccounted in d_{kin} .

Of the 33 BPMG candidates, we find seven *Hipparcos* stars whose parallax distances (d_{hip}) are significantly different from the predicted kinematic distances (d_{kin}); this eliminates them as possible group members. Six have d_{kin} overestimating their true distance; these must be background stars with transverse velocities larger than the BPMG. The other star has d_{kin} underestimating its true distance, in this case the star must be a foreground object moving slower than the BPMG. With those eliminated from the sample, our follow-up observations have focused on the remaining 26 candidates.

4.2. Stellar activity: X-ray emission

We searched for counterparts to the BPMG candidates in the *ROSAT* X-ray catalogs, both the *ROSAT* All-Sky Bright Source Catalog of Voges et al. (1999), and the *ROSAT* All-Sky Survey Faint Source Catalog (Voges et al. 2000). We also searched for counterparts to the known BPMG members. According to Voges et al. (1999), the positional accuracy of the *ROSAT* catalog for point sources is $13''$, 90% of the time, with some outliers possibly having errors as large as $40''$. To make sure we did not overlook possible X-ray counterparts, we have examined all *ROSAT* sources within $50''$ of our BPMG candidates.

We found possible X-ray counterparts for 22 of the known BPMG members, and also to all four of the TW Hya association interlopers. We further found counterparts to six of the BPMG candidates. Of the 32 possible X-ray counterparts, 25 have *ROSAT* positions placing them within $15''$ of the Tycho-2 star, and are thus convincing matches. The other seven sources have large offsets, and were investigated further. A counterpart to TYC 6412-1068-1 (=HD 203), the source 1RX J000648.9-230608, is found with an offset of $24''$. An examination of scans from the Digitized Sky Surveys (DSS) and from 2MASS did not reveal any optical or infrared source within $15''$ of the quoted *ROSAT* position. Furthermore, the *ROSAT* catalog reports a positional error of $19''$ for that X-ray source. Given the larger positional error and the absence of any alternative, we conclude that 1RX J000648.9-230608 is an actual counterpart of TYC 6412-1068-1 (=HD 203). Likewise the *ROSAT* sources 1RXS J184523.4-645201 and 1RXS J184657.3-621037 were found to be near the stars TYC 9077-2487-1 (=HD 172555) and TYC 9073-762-1, with offsets of only $26''$ and $33''$, respectively. The two sources are quoted to have *ROSAT* positional errors of $21''$ and $24''$, and we could not find any other possible match to an optical or infrared source. We thus identify these sources as the actual X-ray counterparts to TYC 9077-2487-1 and TYC 9073-762-1. The star TYC 7760-283-1 has a possible X-ray counterpart (1RXS J121527.9-394843) whose *ROSAT* position is $33''$ from the Tycho-2 position. The quoted *ROSAT* positional uncertainty is $14''$, which would suggest the X-ray source is not a match. However, examination of the DSS and 2MASS reveals no other possible optical counterpart. Because the hardness ratios are consistent with the other BPMG and TW Hya association members, we assume the X-ray source to be a match, although more accurate X-ray astrometry would have to confirm this. Among the new BPMG candidates, we found the

star TYC 643-73-1 to have an associated X-ray source (1RXS J024419.4+105707) with a *ROSAT* position off by $45''$. Again the positional uncertainty quoted in the *ROSAT* catalog is relatively large ($43''$) and we thus conclude that the two are the same object; no other possible counterpart can be seen in the DSS and 2MASS images. The X-ray count rates of all identified counterparts are listed in Tables 1 and 2. We also give the two *ROSAT* hardness ratios *HR1* and *HR2*.

Finally, the star TYC 7443-1102-1 is found to be $26''$ from a *ROSAT* source (1RXS J195602.8-320720) which has a quoted positional accuracy of only $9''$. The source is however not a counterpart to TYC 7443-1102-1.⁸ A close examination of the DSS images reveals that the X-ray source is a near-perfect match to a nearby, fainter star. Interestingly, a search of the USNO-B1.0 reveals that this star has a proper motion $[\mu RA, \mu Decl] = [30, -78]$ mas yr⁻¹ which is nearly coincident with the proper motion of TYC 7443-1102-1, $[\mu RA, \mu Decl] = [30, -66]$. The two stars appear to form a common proper motion pair. Based on the USNO-B astrometry, the companion is at an angular separation $\rho = 26''.3$ from TYC 7443-1102-1, with a position angle $\theta = 316.5$ degrees. Assuming TYC 7443-1102-1 to be a member of the BPMG, the kinematic distance of 45.6 ± 1.6 parsecs suggests a wide binary with projected orbital separation of $1,200 \pm 42$ AU.

To summarize, we find that the majority (21 of 30) of the known BPMG members have X-ray counterparts in the *ROSAT* catalogs, which indicates chromospheric activity consistent with their young ages. Likewise, all four TWA interlopers have bright associated *ROSAT* counterparts. On the other hand, we find X-ray counterparts for only seven of the 33 candidates under investigation (Table 2). This suggests that a significant fraction of the candidates are not young/active and are thus not genuine BPMG members but field stars with projected motions aligned with the projected BPMG velocity vector.

Interestingly, the counterparts of the BPMG candidates have hardness ratios consistent with those of moderately young stars in nearby moving groups. The counterparts are distributed on a locus which coincides roughly with the locus of the known BPMG members (Figure 4). All of them in turn have hardness ratios intermediate between those of extremely young T Tauri stars, and those of the older field K and M dwarfs (Kastner et al. 2003). This suggests that BPMG candidates with X-ray counterparts are likely to be nearby stars of relatively young ages, whether or not they are actual BPMG members.

Because some of the known BPMG members also do not have counterparts in *ROSAT*, we find that the absence of a *ROSAT* counterpart is not sufficient to justify rejection. We thus complement the *ROSAT* data with a spectroscopic search for atomic line emission.

4.3. Stellar activity: H α emission

We have carried out a follow-up program of low-resolution spectroscopy to measure the strength of the H α emission line in BPMG candidates. Targets in the northern sky were observed from MDM observatory on Kitt Peak, with the 2.4 m Hiltner telescope. Spectra were obtained with the MkIII spectrograph, using the thick frontside-illuminated $2K \times 2K$ Loral CCD camera ("Wilbur"), which has a pixel size of $15 \mu\text{m}$. We used the $300 \text{ lines mm}^{-1}$ grating blazed at 8000 \AA in first order

⁸ We thank the referee, J. A. Caballero, for pointing this out.

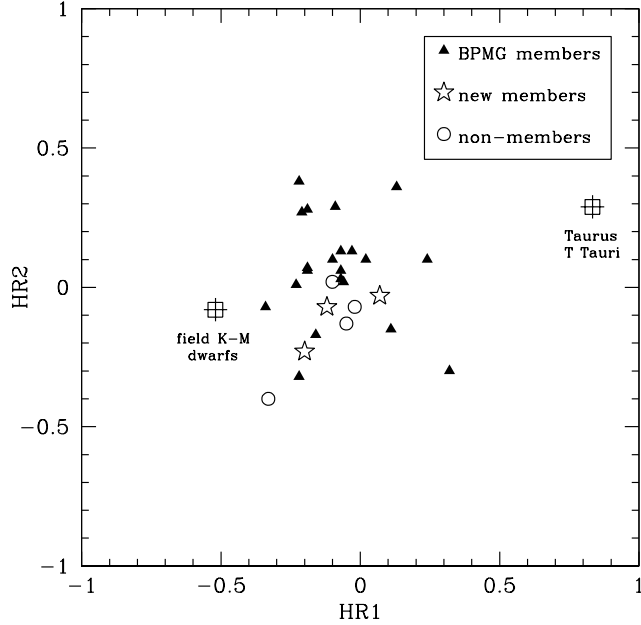


FIG. 4.— X-ray hardness ratio $HR1$ vs. hardness ratio $HR2$ for the stars investigated in this paper. Both $HR1$ and $HR2$ are from the *ROSAT* All-Sky Catalog. The candidates (open symbols) occupy a locus coincident with the known BPMG members (filled triangles), intermediate between the mean locus of older field K and M dwarfs, and the locus of very young T Tauri stars – both values from Kastner et al. (2003) – which have the strongest hardness ratios. The uncertainties for the values from Kastner et al. (2003) are standard errors of the mean; the actual scatter of the individual points is comparable to that of the BPMG members plotted here.

to produce spectra with a resolution of 6.0\AA . With the telescope at $f/7.5$ focal, the spatial scale was $0''.878\text{ pixel}^{-1}$. The $1''.5$ wide, longslit spectra were reduced using IRAF, following standard flatfield correction, sky background subtraction, and spectrum extraction. The wavelength scale was calibrated using an arc spectrum of NeAr. Flux calibration was determined from same-night observations of a set of spectrophotometric standards (Feige 66, Feige 110, Wolf 1346) from Oke (1990). Effective spectral coverage is 5800\AA – 8300\AA .

In the southern sky, spectra were obtained using the 1.5 m telescope operated by the SMARTS consortium at the Cerro Tololo Inter-American Observatory (CTIO). The telescope was equipped with the R-C Cassegrain Spectrograph. We used Grating #47 (800 lines mm^{-1} blazed at 8000\AA) operated in the first order which, with the $110\mu\text{m}$ slit, provides a resolution of 3.1\AA . All the spectra were obtained by service observers (along with calibration arcs and spectrophotometric standards) and kindly processed by F. Walter using the pipeline procedures he wrote and described in Walter et al. (2004).

Spectra were obtained for 31 of the stars under investigation; a subsample is displayed in Figure 5. Spectral types were also recovered from the literature for TYC 3762-1492-1 (=EG Cam) and TYC 1942-2581-1 (=HO Cnc), though both stars were rejected a priori as possible members because of their *Hipparcos* parallax clearly at odds with the predicted moving group distance. Spectral types were determined for all the objects after comparison with spectra from classification standards. Three stars were classified as G dwarfs, all others were found to be either late-type K or early-type M dwarfs. For the M dwarfs, subtypes were calculated based on the strength of the CaH and TiO molecular bands around 7000\AA , as measured

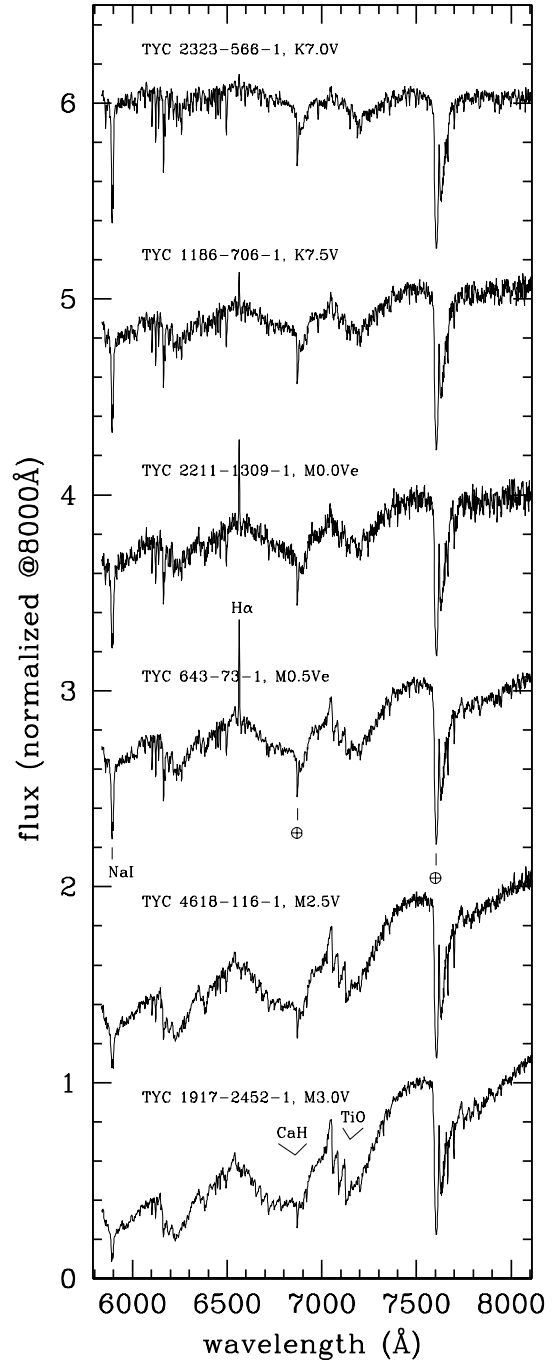


FIG. 5.— Sample medium-resolution spectra of candidate BPMG members. The classification, based on bandstrengths of molecular TiO and CaH, is accurate to 0.5 subtype for late-K and M dwarfs. Some stars clearly show $H\alpha$ in emission, which indicates chromospheric activity. The line is particularly strong in two of the most probable new members of the BPMG: TYC 2211-1309-1 (M0.0e) and TYC 643-73-1 (M0.5e). All spectra are normalized at 8000\AA and shifted vertically by integer values for clarity.

by the TiO5, CaH2, and CaH3 molecular band indices, and following the calibration of Lépine et al. (2003). Subtypes for the M dwarfs are all accurate to ± 0.5 . Subtype assignment for the G and K dwarfs is based on a comparison with spectra from classification standards. Classification of G and K stars using red spectra is however difficult, and some subtypes are accurate to 1-2 subclasses; uncertain subtypes are

noted with a colon (“:”). Spectral classification can be found in the literature for some of these stars; the subtypes generally agree with ours to ± 1 subtype. Many of the former spectral types are based of photographic images from objective prism surveys (Stephenson 1986a,b) some of which are off by more than 1 subtype; in these cases we deem our CCD spectra to be more reliable. Assigned spectral types appear in Table 2.

H α in emission was positively identified in seven stars. The equivalent widths of the H α lines were calculated in IRAF, using the `onedspec` package. The results are shown in Table 2; stars for which we found no evidence of H α in emission are noted as “n.d.” (for “nondetection”). We rejected as possible BPMG member any star showing no significant H α in emission *and* having no counterpart in *ROSAT*. This reduced the list of possible candidates to only six stars, which were targeted for follow-up radial velocity measurement.

4.4. Radial velocity confirmation

Radial velocity observations were obtained using the Cryogenic Echelle Spectrograph (CSHELL), the high-resolution infrared spectrometer at the NASA 3 m Infrared Telescope Facility (IRTF). The detector is a 256×256 InSb array. We set the grating angle to provide $1.5548 \mu\text{m}$ at the center of the array. At this wavelength, CSHELL’s free spectral range is $\sim 730 \text{ km s}^{-1}$ (38 \AA). We used the $0.''5$ slit for a resolution $R \sim 30,000$. The instrumental setup was set by the requirements of the part of our observing program directed toward pre-main-sequence spectroscopic binaries (Simon & Prato 2004) but they are equally well suited for the radial velocity measurements reported here. The spectra were taken as a series of beam-switched, 300 s integrations and were extracted using procedures described in Bender & Simon (2008). The radial velocities were measured by cross-correlation using the same templates as described in Mazeh et al. (2002) and Prato et al. (2002).

We observed six known members of the BPMG in Table 1, and six candidate members from the list compiled in Table 2. Radial velocities were measured and compared to the radial velocities V_{rmg} predicted assuming BPMG membership; results are compiled in Table 3.

All six previously reported BPMG members have predicted radial velocities V_{rmg} within 4.5 km s^{-1} of our observed values, corroborating their BPMG membership. Three of the stars have radial velocity measurements quoted in the literature. TYC 85-1075-1 (=V1005 Ori) is cited by Joy & Mitchell (1948) to have a radial velocity of $+39 \text{ km s}^{-1}$; however this measurement was based on low-dispersion spectrograms and is much less reliable than our own estimate of $+16.6 \pm 1.0 \text{ km s}^{-1}$. The star TYC 7460-137-1 (= AT Mic), was measured by Joy (1947) to have a radial velocity $V_r = -4 \pm 2.4 \text{ km s}^{-1}$, this time using higher dispersion spectrograms. The reported value is largely consistent with our own ($-5.5 \pm 1.5 \text{ km s}^{-1}$). The faint companion to AT Mic, the star NLTT 49691, is quoted in the literature with having a radial velocity $V_r = 3 \pm 2.8 \text{ km s}^{-1}$ (Montes et al. 2001a) which is also consistent with our own measurement ($-3.2 \pm 1.5 \text{ km s}^{-1}$). The close pair is part of a hierarchical triple with TYC 7457-641-1 (=AU Mic). Several radial velocity measurements exist for AU Mic; the most recent documented one is from Wilson (1967), quoting $V_r = +1.6 \pm 3.7 \text{ km s}^{-1}$ which is only slightly off our own measured value.

For candidate members, we find that three stars (TYC 777-141-1, TYC 6806-631-1, and TYC 6849-1795-1) have predicted radial velocities which are inconsistent with the mea-

surements, with differences larger than 15 km s^{-1} ; this indicates that the three stars are interlopers, whose proper motions are only aligned with the projected motion of the BPMG by chance. The other three candidates (TYC 1186-706-1, TYC 7443-1102-1, and TYC 2211-1309-1) have predicted radial velocities in excellent agreement with the observed values, all within 3.5 km s^{-1} , comparable with the small differences observed for the previously known members. All three stars are hereby identified as highly probable members of the BPMG. All three stars also show H α in emission and are X-ray emitters, which suggest they are relatively young and active. We predict that parallax measurements should confirm the distance estimates listed above, as an ultimate test of moving group membership.

For all the stars observed at IRTF, we also estimate the projected rotational velocities $v \sin i$ based of the width of the atomic lines: cross-correlation is optimized using a suite of slow-rotator templates, which are “spun up” using an algorithm based on Gray (1992). The templates are sampled every 2 km s^{-1} (which defines the uncertainty on $v \sin i$). Results are noted in Table 3. Of the three new members, only one (TYC 2211-1309-1) is a moderately fast rotator ($v \sin i = 30 \pm 2 \text{ km s}^{-1}$). The other two have $v \sin i \lesssim 7 \pm 2 \text{ km s}^{-1}$, which suggest either that they are not fast rotators or that the rotation axis makes a small angle with the line of sight. A slow rotation in itself would not, however, rule out the star as a BPMG member. As one can see from Table 3, our measurements indicate that several of the known BPMG members also have relatively small values of $v \sin i$, with TYC 5832-666-1 (=BD-13°6424) having $v \sin i = 7 \pm 2 \text{ km s}^{-1}$.

4.5. Notes on the new BPMG members

4.5.1. TYC 1186-706-1

The star TYC 1186-706-1, which we identify as a K7.5V dwarf, has a predicted distance of 59.7pc. The star was first identified as a red dwarf in the objective prism survey of Stephenson (1986a), based on the strength of its sodium D line; it is star StKM 1-34 in the Stephenson catalog. The star was classified as K5, from a visual inspection of the photographic plate spectrogram. This subtype is broadly consistent with our own classification, although we believe our CCD classification should be considered more reliable.

The star was also identified by Zickgraf et al. (2003) to be the optical counterpart to the X-ray source 1RXS J002334.9+201418 from the *ROSAT* Bright Source Catalogue (RASS-BSC) of Voges et al. (1999), but the star could not be classified because it was too bright and was saturated on the Schmidt plates used in this objective prism survey.

More recently, the star was observed as part of the SuperWASP wide field photometric survey, and discovered to be periodically variable (Norton et al. 2007). The star is cataloged under the name 1SWASP J002334.66+201428.6, and is found to be variable at the 2%-3% level with a period of 7.9 days. Such variation is consistent with rotational modulation.

4.5.2. TYC 7443-1102-1

The star TYC 7443-1102-1 is an M0.0V dwarf, at a predicted distance of 57.7pc. The predicted distance is similar to that of TYC 1186-706-1, but the two stars are in very different directions on the sky (see Figure 1) and must be physically unrelated. TYC 7443-1102-1 does not have any previous mention in the literature. However, the common proper motion companion identified while searching for X-ray counterparts (see Section 4.2 above) is, of course, the known X-ray

source J195602.8-320720 (Voges et al. 1999). We associate this X-ray source with the proper motion star USNO-B1.0 0578-1079977. Its position is listed in Table 3.

The companion has a visual magnitude $V \approx 13.6$ mag (estimated from photographic plate measurements), compared with $V_T = 11.95$ mag for TYC 7443-1102-1. The companion should also be considered a new member of the β Pic moving group.

4.5.3. TYC 2211-1309-1

The fourth new member, TYC 2211-1309-1, is an M0.0Ve red dwarf at a predicted distance of 45.6 pc. This object was first prosaically identified as a “noncluster X-ray source (Star?)” by Böhringer et al. (2000), in a search for galaxy clusters among *ROSAT* sources. The object was identified by Fuhrmeister & Schmitt (2003) as a variable X-ray source with flaring behavior. This would be consistent with chromospheric activity on that star.

This star was also identified in the SuperWASP wide field photometric survey of Norton et al. (2007) and found to be variable in the optical regime. The star is cataloged under the name 1SWASP J220041.59+271513.5, and was observed to be variable at the 2% level, with a period of 0.52 days. This behavior suggests rotational modulation in a fast rotator, and is consistent with the high value of $v \sin i$ we infer for the rotational velocity. An early M-type star with a rotation period of 0.5 days, having a radius of about $0.5 R_\odot$ (Berger et al. 2006), would be expected to have a rotation velocity at the equator of 50 km s^{-1} , consistent with our inferred value of $v \sin i = 30 \text{ km s}^{-1}$.

5. CONCLUSIONS

We have presented an algorithm to identify probable members of any known nearby moving group from large catalogs of proper motion stars. The technique identifies prospective members based on the orientation of their proper motion vec-

tor, which aligns with the projected motion of the group in the plane of the sky, and uses the magnitude of the proper motion to estimate a distance of the assumption of group membership. That predicted distance is used to verify consistency with the known color-magnitude relationship of the group.

We have tested the method by conducting a search for possible members of the β Pictoris moving group in a subsample of high proper motion stars $\mu > 70 \text{ mas}^{-1}$ from the Tycho-2 catalog. A subset of 31 candidates was investigated for signs of youth, including low-resolution spectroscopy to look for $H\alpha$ lines in emission, and a search for X-ray counterparts in the *ROSAT* catalogs. Twelve stars showing possible evidence for youth were targeted for high-resolution infrared spectroscopy, in order to corroborate moving group membership from their radial velocities. Three of the stars are found to be convincing new members of the BPMG, these are TYC 1186-706-1, TYC 7443-1102-1, and TYC 2211-1309-1. The star TYC 7443-1102-1 is also found to have a common proper motion companion, with an angular separation of $26''$, which is most probably a wide companion with a projected separation $\approx 1,200 \text{ AU}$.

We believe that the method can be successfully expanded to the identification of members from any other moving group and association. The use of a deeper proper motion catalog, such as the recent PPM-Extended (PPMX) catalog (Röser et al. 2008), which extends to $V=15$ mag, or the SUPERBLINK database (Lépine & Shara 2005) that is statistically complete to $V=19$ mag, should allow for the identification of most low-mass members of these moving groups, at least down to the hydrogen burning limit.

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TABLE 1
RECOVERED β PICTORIS MOVING GROUP MEMBERS

TYC	HIP	Alt. name	α (ICRS) ^a (2000.0) ^d	δ (ICRS) ^a (2000.0) ^d	μ_α mas yr ⁻¹	μ_δ mas yr ⁻¹	V_T mag	K_s mag	d_{kin}^b pc	d_{hip}^c pc	X-ray CR ^e ks ⁻¹	HR1 ^f	HR2 ^f
6412 1068 1	560	HD 203	1.708454	-23.107429	97.1	-47.4	6.18	5.24	39.4±0.3	39.4±0.6	44±15	0.32±0.32	-0.30±0.37
1777 1480 1	10679	BD+28°382B	34.352851	28.741941	86.7	-76.7	7.76	6.26	37.4±0.9	27.3±4.4	364±73	-0.03±0.20	0.13±0.28
1777 1479 1	10680	HD 14082	34.355136	28.745208	84.3	-77.6	7.04	5.78	37.8±0.7	34.5±3.4	...	...	...
45 990 1	11360	HD 15115	36.567489	6.292664	100.7	5.5	6.79	5.82	38.7±0.5	45.2±1.3	77±20	0.04±0.25	-0.61±0.55
2323 566 1	11437	AG Tri	36.871692	30.973667	84.0	-71.8	10.08	7.08	39.2±1.1	40.0±3.6	566±46	-0.16±0.07	-0.17±0.12
4739 1551 1	21547	c Eri	69.400451	-2.473389	43.6	-64.1	5.21	4.53	32.2±0.4	29.4±0.3	...	...	...
85 1075 1	23200	V1005 Ori	74.895042	1.783751	38.1	-94.4	10.10	6.26	25.5±0.5	25.9±1.7	651±42	-0.19±0.06	0.28±0.10
8513 572 1	23309	CD-57°1054	75.196235	-57.257244	36.2	72.6	10.11	6.24	24.3±0.7	26.8±0.8	330±52	0.11±0.15	-0.15±0.18
689 130 3	23418	[RHG95]853	75.494987	9.983299	17.2	-82.0	11.74	6.37	36.4±4.8	33.2±10.5	661±59	-0.34±0.08	-0.07±0.14
8099 1392 1	27321	β Pic	86.821182	-51.066703	4.1	83.3	3.85	3.52	17.1±0.3	19.4±0.1	...	...	...
9172 690 1	29964	AO Men	94.617607	-72.045021	-8.5	75.7	9.99	6.81	37.2±0.7	38.6±1.3	1030±30	-0.07±0.02	0.03±0.04
8704 1271 1	76629	V343 Nor	234.740005	-57.707344	-46.2	-97.9	8.16	5.85	40.6±0.6	39.8±1.7	1420±72	-0.07±0.05	0.13±0.07
6805 1909 1	79881	d Sco	244.574661	-28.613777	-32.4	-100.2	4.78	4.73	37.9±0.3	41.3±0.4	...	...	...
9064 3514 1	84586	V824 Ara	259.356384	-66.950714	-21.6	-136.4	6.87	4.70	31.5±0.3	31.4±0.5	476±27	-0.06±0.05	0.02±0.08
8369 1619 1	88399	HD 164249	270.764190	-51.648807	2.8	-87.2	7.01	5.91	50.2±0.6	48.1±1.3	150±42	0.13±0.29	0.36±0.36
7911 5035 1	88726	HD 165189	271.707855	-43.424964	13.8	-105.3	5.63	4.38	40.2±0.9	41.8±1.2	...	...	...
9077 2487 1	92024	HD 172555	281.361907	-64.870918	32.9	-148.2	4.77	4.29	28.8±0.2	28.5±0.2	97±31	-0.22±0.33	-0.32±0.67
9073 762 1	...	...	281.718963	-62.176612	18.1	-76.6	12.22	7.85	55.8±3.5	...	137±38	-0.22±0.29	0.38±0.43
7408 54 1	...	...	282.685302	-31.796323	10.6	-77.8	11.30	7.46	51.1±1.9	...	308±37	-0.19±0.11	0.07±0.19
8381 2435 1	92680	PZ Tel	283.274414	-50.180332	15.8	-84.1	8.41	6.36	51.2±0.7	51.5±2.6	1000±88	0.02±0.08	0.10±0.12
8765 2571 1	95261	HD 181296	290.713256	-54.423740	25.0	-83.1	5.02	5.00	50.8±0.7	48.2±0.5	...	...	...
8765 638 1	95270	HD 181327	290.745513	-54.537860	24.1	-82.9	7.04	5.91	51.1±0.9	51.8±1.7	...	...	...
6909 1892 1	99273	HD 191089	302.271636	-26.223878	-52.4	-58.8	7.19	6.07	51.6±0.9	52.2±1.2	73±18	-0.30±0.22	0.07±0.40
7460 137 1	102141	AT Mic	310.462432	-32.434368	261.3	-344.8	11.24	4.94	9.8±0.1	10.7±0.4	3910±120	-0.19±0.03	0.06±0.04
7457 641 1	102409	AU Mic	311.288940	-31.340036	278.8	-360.0	8.77	4.52	9.3±0.1	9.9±0.1	5950±121	-0.07±0.02	0.06±0.03
6348 98 1	103311	HD 199143	313.948486	-17.114032	62.2	-65.4	7.32	5.81	44.6±1.0	45.7±1.6	1400±107	0.24±0.07	0.10±0.09
6349 200 1	...	AZ Cap	314.011260	-17.181446	59.3	-63.0	10.63	7.03	46.6±2.3	...	236±26	-0.23±0.10	0.01±0.17
9340 437 1	...	CPD-72°2713	340.703155	-71.705772	94.1	-54.4	10.54	6.89	36.7±0.7	...	727±78	-0.21±0.10	0.27±0.16
5832 666 1	...	BD-13°6424	353.128265	-12.264112	138.1	-83.2	10.71	6.56	27.3±0.4	...	620±48	-0.10±0.07	0.10±0.11
TW Hya association (TWA) interlopers													
7190 2111 1	...	...	160.625610	-33.671215	-122.2	-29.3	10.92	6.89	30.2±0.6	...	324±31	-0.08±0.09	0.05±0.14
7208 347 1	53911	TW Hya	165.466476	-34.704719	-73.4	-17.5	11.27	7.29	52.0±1.6	53.7±6.2	571±43	0.58±0.06	-0.12±0.08
7201 27 1	...	...	167.307785	-30.027683	-90.0	-87.7	11.16	6.71	43.6±2.0	...	341±35	-0.22±0.09	-0.02±0.15
7760 283 1	...	...	183.878219	-39.811759	-75.9	-26.3	11.43	7.30	52.8±1.6	...	375±65	-0.31±0.16	0.31±0.27

^a Right ascension (α) and declinations (δ) are given in the International Celestial Reference System (ICRS) and at the epoch 2000.0, as provided by the Tycho-2 catalog. ^b Kinematic distance based on proper motion and assumed group membership. ^c Geometric distance based on the Hipparcos parallax. ^d Epoch of the ICRS coordinates. ^e ROSAT X-ray count rate. ^f ROSAT X-ray hardness ratio.

TABLE 2
CANDIDATE β PICTORIS MOVING GROUP MEMBERS

TYC	HIP	Alt. name	α (ICRS) ^a (2000.0) ^d	δ (ICRS) ^a (2000.0) ^d	μ_α mas yr ⁻¹	μ_δ mas yr ⁻¹	V_T mag	K_s mag	d_{kin}^b pc	d_{hip}^c pc	X-ray CR ^e ks ⁻¹	HR1 ^f	HR2 ^f	Sp. type	EW(H α)	BPMG member?
1186 706 1	...	...	5.894279	20.241407	63.0	-38.1	10.85	7.33	59.7 \pm 1.6	...	176 \pm 27	-0.12 \pm 0.15	-0.07 \pm 0.24	K7.5V	-0.7 \pm 0.1	table 3
5853 933 1	...	BPM 47010	18.914964	-21.514326	81.4	-22.5	13.03	8.52	45.9 \pm 2.0	...	...	...	...	K7.0V	n.d.	no
643 73 1	12787	...	41.088851	10.961535	73.5	-57.3	11.40	7.11	41.9 \pm 1.2	34.9 \pm 3.7	301 \pm 94	-0.33 \pm 0.32	-0.40 \pm 0.94	M0.5Ve	-3.4 \pm 0.1	no
3333 1029 1	...	...	64.939537	47.758914	21.2	-79.0	11.32	7.69	53.5 \pm 3.1	...	...	...	...	M0.0V	n.d.	no
2384 1106 1	...	HD 279890	66.975112	35.936912	29.8	-64.5	10.82	7.20	58.7 \pm 4.1	...	...	...	...	K0V:	n.d.	no
3762 1492 1	28368	EG Cam	89.907287	58.593612	11.2	-252.9	10.27	6.21	17.4 \pm 0.2	13.5 \pm 0.3	...	...	...	M0.5V ^g	...	no
8895 225 1	31878	CD-61 $^\circ$ 1439	99.958557	-61.478378	-25.7	71.3	9.69	6.50	29.3 \pm 1.0	22.4 \pm 0.5	143 \pm 14	-0.05 \pm 0.09	-0.13 \pm 0.13	K5V:	n.d.	no
2443 845 1	...	StKM 1-603	100.331420	33.907360	-25.6	-68.1	11.33	7.96	55.8 \pm 2.8	...	...	...	...	M0.0V	n.d.	no
1903 1306 1	34222	GJ 265A	106.426132	27.471057	-49.2	-97.2	10.26	6.78	35.8 \pm 0.7	23.9 \pm 1.3	...	...	...	K7.0V	n.d.	no
1917 2452 1	35191	GJ 9227	109.082481	27.142967	-39.0	-191.6	10.75	6.18	20.0 \pm 0.6	12.0 \pm 0.3	...	...	...	M3.0V	n.d.	no
4618 116 1	...	...	109.992683	84.077461	-38.5	-86.0	11.93	7.51	41.8 \pm 1.3	...	...	...	...	M2.5V	n.d.	no
777 141 1	...	...	113.734748	14.765309	-80.1	-106.4	10.74	6.39	26.4 \pm 0.7	...	...	...	...	M3.0Ve	-3.3 \pm 0.1	table 3
9389 53 1	...	...	117.695777	-79.867774	-48.0	57.7	11.18	7.81	44.5 \pm 2.1	...	...	...	...	K3V:	n.d.	no
1942 2581 1	42253	HO Cnc	129.232696	23.246904	-108.7	-106.7	9.51	6.41	26.8 \pm 0.4	44.1 \pm 2.7	...	...	...	K5V ^h	...	no
1952 1263 1	...	StKM 1-764	139.756805	23.597393	-49.6	-55.0	11.92	8.36	57.4 \pm 1.8	...	...	...	...	K7.5V	n.d.	no
240 2164 1	48447	...	148.163299	3.130231	-61.6	-33.7	10.56	7.07	57.8 \pm 1.5	22.7 \pm 1.4	...	...	...	K7.5V	n.d.	no
8606 821 1	...	...	149.721710	-57.824100	-165.9	36.5	11.88	6.44	19.4 \pm 0.5	...	...	...	...	M4.5V	n.d.	no
7732 1096 1	...	...	164.767608	-41.300849	-118.8	-75.4	11.84	7.12	27.2 \pm 0.7	...	...	...	...	M1.5V	n.d.	no
7322 67 1	...	LTT 6184	232.204833	-34.332885	-104.2	-118.5	9.04	5.77	26.9 \pm 0.3	...	...	...	...	G9V:	n.d.	no
8304 1011 1	...	...	233.453536	-49.300254	-138.3	-213.6	11.16	6.47	17.3 \pm 0.3	...	...	...	...	K3V:	n.d.	no
6778 560 1	...	BD-22 $^\circ$ 4030	237.258209	-23.042593	-51.5	-74.5	10.01	6.89	43.2 \pm 1.2	...	...	...	...	G5V:	n.d.	no
5046 481 1	...	BD-05 $^\circ$ 4273	244.614517	-6.074768	-32.5	-78.8	10.05	6.50	36.1 \pm 1.1	...	...	...	...	K0V:	n.d.	no
1513 989 1	...	HD 147926	245.998031	20.394264	-63.6	-47.1	8.13	4.96	21.7 \pm 0.3	...	...	...	...	K2V:	n.d.	no
6806 631 1	...	HD 147611	246.008605	-29.178794	-42.3	-139.5	10.15	6.77	27.4 \pm 0.5	...	505 \pm 39	-0.02 \pm 0.07	-0.07 \pm 0.11	K5V:	-0.3 \pm 0.1	table 3
7892 2635 1	...	...	264.482879	-42.324363	-11.6	-107.2	11.60	7.45	39.4 \pm 1.2	...	...	...	...	M1.5V	n.d.	no
6832 549 1	...	...	266.221771	-25.644212	-14.7	-82.5	11.03	7.49	44.5 \pm 2.4	...	...	...	...	K2V:	n.d.	no
6849 1795 1	...	...	268.725524	-26.827995	18.1	-103.5	10.28	6.91	36.0 \pm 1.0	...	563 \pm 45	-0.10 \pm 0.08	0.02 \pm 0.12	K5V:	-1.1 \pm 0.1	table 3
6262 1013 1	...	...	268.909790	-22.320178	-9.6	-70.4	11.71	7.75	50.5 \pm 3.2	...	...	...	...	K0V:	n.d.	no
7899 6490 1	...	HD 324810	270.559997	-37.682273	18.9	-185.5	11.95	6.97	22.2 \pm 0.5	...	...	...	...	...	n.d.	no
7443 1102 1	...	...	299.018127	-32.126995	31.2	-65.0	11.80	7.84	57.7 \pm 2.8	...	...	...	...	M0.0V	-0.4 \pm 0.1	table 3
2211 1309 1	...	...	330.173126	27.253810	76.3	-14.7	11.37	7.72	45.6 \pm 1.6	...	219 \pm 22	-0.20 \pm 0.09	-0.23 \pm 0.15	M0.0Ve	-2.6 \pm 0.4	table 3
4275 1683 1	...	...	330.877685	66.683044	72.6	14.5	11.19	7.85	45.6 \pm 1.6	...	...	...	...	K7.5V	n.d.	no
4285 2546 1	...	...	357.159545	62.026763	77.9	-8.6	11.34	7.58	49.5 \pm 2.2	...	...	...	...	K5.0V	n.d.	no

^a Right ascension (α) and declinations (δ) are given in the International Celestial Reference System (ICRS) and at the epoch 2000.0, as provided by the Tycho-2 catalog. ^b Kinematic distance based on proper motion and assumed group membership. ^c Geometric distance based on the Hipparcos parallax. ^d Epoch of the ICRS coordinates. ^e ROSAT X-ray count rate. ^f ROSAT X-ray hardness ratio. ^g Spectral type from Reid et al. (1995) ^h Spectral type from Montes et al. (2001a)

TABLE 3
RESULTS FROM HIGH-RESOLUTION INFRARED SPECTROSCOPY

TYC	Alt. name	α (ICRS) (2000.0)	δ (ICRS) (2000.0)	V_{rmg}^a (km s $^{-1}$)	V_r^b (km s $^{-1}$)	$v \sin i^c$ (km s $^{-1}$)	Sp. type	BPMG member?
Previously known BPMG members								
85-1075-1	V1005 Ori	74.895042	1.783751	+17.7	+16.6 \pm 1.0	12 \pm 2	M0.5Ve	yes
7408-54-1	...	282.685302	-31.796323	-9.6	-7.1 \pm 1.5	50 \pm 2	K7Ve	yes
7460-137-1	AT Mic	310.462432	-32.434368	-5.9	-5.5 \pm 1.5	15 \pm 2	M4.0Ve	yes
...	NLTT 49691 ^d	310.463112	-32.436175	-5.9 \pm	-3.2 \pm 1.5	12 \pm 2	M4.0V	yes
7457-641-1	AU Mic	311.288940	-31.340036	-6.0	-6.7 \pm 1.5	12 \pm 2	M1.0Ve	yes
6349-200-1	AZ Cap	314.011260	-17.181446	-9.2	-4.7 \pm 1.5	20 \pm 2	K5Ve	yes
5832-666-1	BD-13 $^{\circ}$ 6424	353.128265	-12.264112	+0.6	+0.5 \pm 1.5	7 \pm 2	M0.5Ve	yes
New BPMG candidates								
1186-706-1	...	5.894279	20.241407	-1.5	-5.0 \pm 1.5	7 \pm 2	K7.5V	yes
777-141-1	...	113.734748	14.765309	+13.5	+31.4 \pm 1.0	6 \pm 2	M3.0Ve	no
6806-631-1	HD 147611	246.008605	-29.178794	-9.7	+7.4 \pm 1.0	4 \pm 2	K4V:	no
6849-1795-1	...	268.725524	-26.827995	-11.7	-28.4 \pm 1.5	25 \pm 2	K4V:	no
7443-1102-1	...	299.018127	-32.126995	-7.8	-8.8 \pm 1.5	6 \pm 2	M0.0V	yes
...	1RXS J195602.8-320720 ^e	299.012262	-32.121850	...	...	...	...	yes
2211-1309-1	...	330.173126	27.253810	-12.7	-13.3 \pm 2.4	30 \pm 2	M0.0Ve	yes

^a Predicted radial velocity assuming the star to be a BPMG member. ^b Radial velocity measured from high-resolution infrared spectroscopy (IRTF). ^c Measured rotational velocity. ^d Resolved companion to TYC 7460-137-1, with angular separation $\rho = 3.349 \pm 0.007$ (). ^e Common proper motion companion to TYC 7443-1102-1